

PHOTOPRODUCTION OF A $\pi\rho$ PAIR AND TRANSVERSITY GPDs

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We demonstrate that the chiral-odd transversity generalized parton distributions (GPDs) of the nucleon can be accessed through the exclusive photoproduction process $\gamma + N \rightarrow \pi + \rho + N'$, in the kinematics where the meson pair has a large invariant mass and the final nucleon has a small transverse momentum, provided the vector meson is produced in a transversely polarized state. We calculate perturbatively the scattering amplitude at leading order in α_s . We build a simple model for the dominant transversity GPD $H_T(x, \xi, t)$ based on the concept of double distribution. Counting rates estimates show that the experiment looks feasible with the real photon beam characteristics expected at JLab@12 GeV, in low Q^2 lepton production at Jlab@12 GeV and in the COMPASS experiment.

Keywords: Generalised Parton Distributions, Exclusive Processes

1. Chiral-odd GPDs and factorization

Transversity quark distributions in the nucleon remain among the most unknown leading twist hadronic observables, mainly due to their chiral-odd character which enforces their decoupling in most hard amplitudes. After the pioneering studies of Ref. 1, much work² has been devoted to the study of many channels but experimental difficulties have challenged the most promising ones.

On the other hand, tremendous progress has been recently witnessed on the QCD description of hard exclusive processes, in terms of generalized parton distributions (GPDs) describing the 3-dimensional content of hadrons. Access to the chiral-odd transversity GPDs,³ noted H_T , E_T , \tilde{H}_T , \tilde{E}_T , has however turned out to be even more challenging⁴ than the usual transversity distributions: one photon or one meson electroproduction lead-

ing twist amplitudes are insensitive to transversity GPDs. The strategy which we follow here, as initiated in Ref. 5, is to study the leading twist contribution to processes where more mesons are present in the final state. A similar strategy has also been advocated recently in Ref. 6 for chiral-even GPDs. We advocate that the hard scale which allows to probe the short distance structure of the nucleon is $s = M_{\pi\rho}^2 \sim |t'|$ in the fixed angle regime. In the example developed previously,⁵ the process under study was the high energy photo (or electro) diffractive production of two vector mesons, the hard probe being the virtual “Pomeron” exchange (and the hard scale was the virtuality of this pomeron), in analogy with the virtual photon exchange occurring in the deep electroproduction of a meson.

We study here⁷ a process involving a transversely polarized ρ meson in a 3-body final state:

$$\gamma + N \rightarrow \pi + \rho_T + N'. \quad (1)$$

It is a priori sensitive to chiral-odd GPDs due to the chiral-odd character of the leading twist distribution amplitude (DA) of ρ_T . The estimated rate depends of course much on the magnitude of the chiral-odd GPDs. Not much is known about them, but model calculations have been developed in Refs. 5,8–10 and a few moments have been computed on the lattice.¹¹ To factorize the amplitude of this process we use the now classical proof of the factorization of exclusive scattering at fixed angle and large energy.¹² The amplitude for the process $\gamma + \pi \rightarrow \pi + \rho$ is written as the convolution of mesonic DAs and a hard scattering subprocess amplitude $\gamma + (q + \bar{q}) \rightarrow (q + \bar{q}) + (q + \bar{q})$ with the meson states replaced by collinear quark-antiquark pairs. We then extract from the factorization procedure of the deeply virtual Compton scattering amplitude near the forward region the right to replace one entering meson DA by a $N \rightarrow N'$ GPD, and thus get Fig. 1. The needed skewness parameter ξ is written in terms of the meson pair squared invariant mass $M_{\pi\rho}^2$ as

$$\xi = \frac{\tau}{2 - \tau} \quad , \quad \tau = \frac{M_{\pi\rho}^2}{S_{\gamma N} - M^2}. \quad (2)$$

Indeed the same collinear factorization property bases the validity of the leading twist approximation which either replaces the meson wave function by its DA or the $N \rightarrow N'$ transition by nucleon GPDs. A slight difference is that light cone fractions $(z, 1 - z)$ leaving the DA are positive, while the corresponding fractions $(x + \xi, \xi - x)$ may be positive or negative in the case of the GPD. Our Born order calculation shows that this difference does not ruin the factorization property.

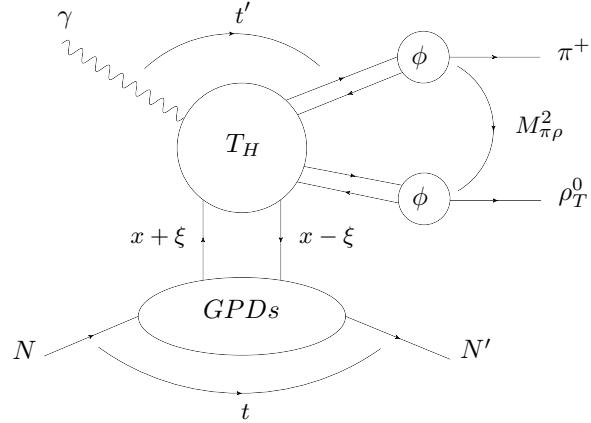


Fig. 1. Factorization of the amplitude for $\gamma + N \rightarrow \pi + \rho + N'$ at large $M_{\pi\rho}^2$.

In order for the factorization of a partonic amplitude to be valid, and the leading twist calculation to be sufficient, one should avoid the dangerous kinematical regions where a small momentum transfer is exchanged in the upper blob, namely small $t' = (p_\pi - p_\gamma)^2$ or small $u' = (p_\rho - p_\gamma)^2$, and the resonance regions for each of the invariant squared masses $(p_\pi + p_{N'})^2$, $(p_\rho + p_{N'})^2$, $(p_\pi + p_\rho)^2$.

Let us finally stress that our discussion applies as well to the case of electroproduction where a moderate virtuality of the initial photon may help to access the perturbative domain with a lower value of the hard scale $M_{\pi\rho}$.

2. The scattering amplitude

The scattering amplitude of the process (1) is written in the factorized form:

$$\mathcal{A}(t, M_{\pi\rho}^2, u') = \int_{-1}^1 dx \int_0^1 dv \int_0^1 dz T^q(x, v, z) H_T^q(x, \xi, t) \Phi_\pi(z) \Phi_\perp(v), \quad (3)$$

where T^q is the hard part of the amplitude and the transversity GPD of a parton q in the nucleon target which dominates at small momentum transfer is defined³ by

$$\begin{aligned} & \langle N'(p_2), \lambda' | \bar{q} \left(-\frac{y}{2} \right) \sigma^{+j} \gamma^5 q \left(\frac{y}{2} \right) | N(p_1), \lambda \rangle \\ &= \bar{u}(p', \lambda') \sigma^{+j} \gamma^5 u(p, \lambda) \int_{-1}^1 dx e^{-\frac{i}{2}x(p_1^+ + p_2^+)y^-} H_T^q, \end{aligned} \quad (4)$$

where λ and λ' are the light-cone helicities of the nucleon N and N' . The chiral-odd DA for the transversely polarized meson vector ρ_T , is defined, in leading twist 2, by the matrix element

$$\langle 0 | \bar{u}(0) \sigma^{\mu\nu} u(x) | \rho_T^0(p, \epsilon_{\pm}) \rangle = \frac{i}{\sqrt{2}} (\epsilon_{\pm}^{\mu}(p) p^{\nu} - \epsilon_{\pm}^{\nu}(p) p^{\mu}) f_{\rho}^{\perp} \int_0^1 du e^{-iup \cdot x} \phi_{\perp}(u) \langle 5 \rangle$$

where $\epsilon_{\pm}^{\mu}(p_{\rho})$ is the ρ -meson transverse polarization and with $f_{\rho}^{\perp} = 160$ MeV. Two classes of Feynman diagrams without (Fig. 2) and with (Fig. 3) a 3-gluon vertex describe this process.

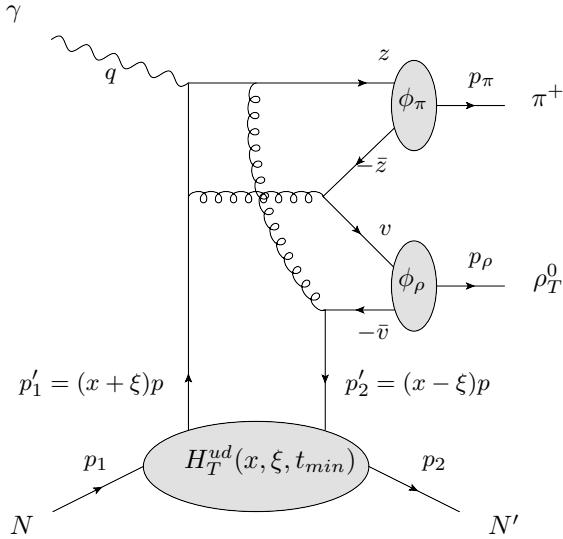


Fig. 2. Sample diagram without a 3-gluon vertex.

The scattering amplitude gets both a real and an imaginary part. Integrations over v and z have been done analytically whereas numerical methods are used for the integration over x .

3. Results

Various observables can be calculated with this amplitude. We stress that even the unpolarized differential cross-section $\frac{d\sigma}{dt du' dM_{\pi\rho}^2}$ is sensitive to the transversity GPD. To estimate the rates, we modelize the dominant

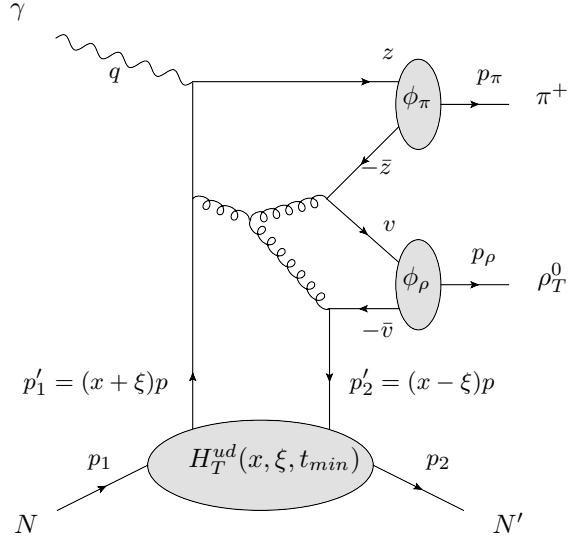


Fig. 3. Sample diagram with a 3 gluon vertex.

transversity GPD $H_T^q(x, \xi, t)$ ($q = u, d$) in terms of double distributions

$$H_T^q(x, \xi, t = 0) = \int_{\Omega} d\beta d\alpha \delta(\beta + \xi\alpha - x) f_T^q(\beta, \alpha, t = 0), \quad (6)$$

with $\Omega = \{|\alpha|^2 + |\beta|^2 \leq 0\}$ and where f_T^q is the quark transversity double distribution written as

$$f_T^q(\beta, \alpha, t = 0) = \Pi(\beta, \alpha) \delta q(\beta) \Theta(\beta) - \Pi(-\beta, \alpha) \delta \bar{q}(-\beta) \Theta(-\beta), \quad (7)$$

where $\Pi(\beta, \alpha) = \frac{3}{4} \frac{(1-\beta)^2 - \alpha^2}{(1-\beta)^3}$ is a profile function and $\delta q, \delta \bar{q}$ are the quark and antiquark transversity parton distribution functions of Ref. 13. The t -dependence of these chiral-odd GPDs - and its Fourier transform in terms of the transverse localization of quarks in the proton¹⁴ - is very interesting but completely unknown. We describe it in a simplistic way using a dipole form factor:

$$H_T^q(x, \xi, t) = H_T^q(x, \xi, t = 0) \times \frac{C^2}{(t - C)^2} \quad (C = 0.71 \text{ GeV}^2). \quad (8)$$

In Fig. 4, we show the M_{ρ}^2 dependence of the differential cross section $d\sigma/dM_{\rho}^2$ for JLab kinematics ($s_{\gamma N} = 20 \text{ GeV}^2$). On the same plot, we show the similar cross section for the case where the ρ meson is longitudinally polarized. Note that in this case (which will be discussed in detail in a

forthcoming publication), the GPDs which contribute are the usual chiral even ones, parametrized here through the usual double distribution ansatz.

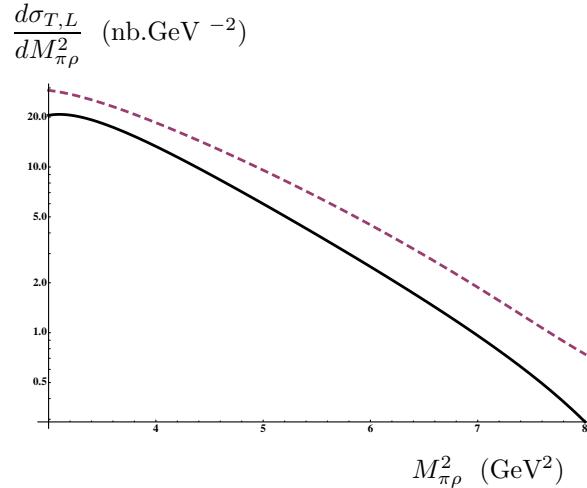


Fig. 4. Differential cross section $\frac{d\sigma}{dM_{\pi\rho}^2}$ at $s_{\gamma N} = 20$ GeV 2 for the process $\gamma p \rightarrow \pi^+ \rho^0 n$ for a transversely polarized (full curve) and a longitudinally polarized (dashed curve) ρ meson. The cuts are discussed in detail in Ref. 7.

Rate estimates⁷ show that expected luminosities at JLab (after the 12 GeV energy increase) and at the Compass experiment at CERN are sufficient to gather a sample of interesting events allowing this physics to be experimentally tested.

Note that in the case of leptoproduction, the virtuality Q^2 of the exchanged photon plays no crucial role in our process, and the virtual photoproduction cross section is almost Q^2 -independent if we choose to select events in a sufficiently narrow Q^2 -window ($0.02 < Q^2 < 1$ GeV 2), which is legitimate since the effective photon flux is strongly peaked at very low values of Q^2 . This procedure applied to muoproduction at Compass yields a rate sufficient to get an estimate of the transversity GPDs in the region of small ξ (~ 0.01).

Target transverse spin asymmetries need to consider nucleon helicity flip amplitudes, i.e. the effect of $E_T(x, \xi, t)$ and/or $\bar{E}_T(x, \xi, t)$ GPDs. This will be studied later on.

In conclusion, we expect the process discussed here to be observable in two quite different energy ranges, which should give complementary information on the chiral-odd transversity GPDs: the large ξ region may be

scrutinized at JLab and the smaller ξ region may be studied at COMPASS. Let us stress that our study is built on known leading twist factorization theorems, i.e. the scattering amplitude involves only leading twist non-perturbative components. This stays in contrast with other attempts to access transversity GPDs.¹⁵

Acknowledgments

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